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CONTRIBUTION OF SCIENCE TO THE UNDERSTANDING AND CONTROL OF PLANT DISEASES

By E.C. STAKMAN,
Institute of Agriculture,
University of Minnesota,
St. Paul, Minnesota

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CONTRIBUTION OF SCIENCE TO THE UNDERSTANDING AND CONTROL OF PLANT DISEASES

No. 720

C.4.2

By: E. C. Stakman
Institute of Agriculture
University of Minnesota
St. Paul, Minnesota

1. The control of plant diseases is of vital importance in a hungry world. Food is man's most basic need, for science has not yet learned how to sustain human life without it. Nor has man learned how to make food; plants make it for him. Whether he eats the plants directly or feeds them to animals in order that he may have meat and milk, man is completely dependent on plants for his earthly existence. As the number of human beings is increasing at a high rate in the world as a whole, and at an alarming rate in many of the hungrier areas of the world, there is a growing realization that food and feed production must keep pace with human reproduction if we are to avert disaster. It is therefore pertinent to ask: what are the principal obstacles to increased food production; how and to what extent can they be overcome?

2. Poor plants, poor soil, bad weather, weeds, insects, diseases, human ignorance, and human apathy are the most formidable barriers to progress in increasing the productivity of lands available for agricultural production. As the amount of agricultural land in many countries is so strictly limited, primary effort must be devoted to maximizing yields per unit area. Naturally, it also is desirable to increase the efficiency of production by decreasing the amount of labor and other costs. But the most critical factor in many hungry countries is scarcity of food and the land to produce it; hence the basic need is biologic efficiency, with as much economic efficiency as is practicable in satisfying the basic need. Much has been accomplished in replacing poor varieties of basic food crops by better ones and by converting poor soils into better ones. The better-bred and better-fed varieties have high yielding potential; and it is urgent that the potential be attained, not only under favorable conditions but also in the face of adversity. The destructive effects of bad weather, bad pests, and bad pathogens must be prevented or reduced by utilizing the best methods available at present and by devising better ones for the future.

3. The cooperative effort of several groups of scientific specialists obviously is needed to understand and mitigate the destructive effects of the numerous interrelated agents of destruction of economic plants and their harvested products. The enemies of plants useful to man are the enemies of mankind; they must be fought intelligently and persistently, with adequate scientific and educational weapons; for they belong to the triumvirate of man's worst enemies: diseases of economic plants and animals, human diseases, and human prejudice and perversity. But how important are plant pests and diseases?

4. Plant diseases, insects, and weeds reduce the potential agricultural production of the United States almost 23 per cent annually. This represents the approximate equivalent of the production from 75 million acres of crop land and 150 million acres of range and pasture lands, enough to subsist 50 million human

beings. Plant diseases alone cost the United States upwards of $10 billion annually and reduce agricultural production at least 10 per cent. This is deplorable but not necessarily dangerous in food surplus countries like the United States. But losses are higher and much more tragic in their consequences in many countries which are always near the danger line in respect of food supplies.

5. Certain diseases can suddenly and unexpectedly cause widespread and devastating epidemics in all important food and feed crops, thus causing economic distress in most countries and critical food shortages in many. At least a million people died of starvation in India in 1943 because of an epidemic of Helminthosporium blight of rice. Within the past few years there have been destructive epidemics of one or more of the three wheat rusts in important wheat-producing countries of every continent, with losses in the epidemic areas ranging from 40 to 80 per cent. As examples, in 1951 stem rust alone caused a loss of 40 per cent of the durum wheat crop in Chile and 50 per cent of the spring wheat crop in Sweden. In two successive years, 1953 and 1954, stem rust destroyed 75 per cent of the durum crop and about 25 per cent of the spring bread wheat in the United States, with heavy losses in Canada also. As this is being written, in July and August of 1962, destructive epidemics of yellow rust have just taken a heavy toll of wheat in Southern Colombia and Ecuador, and stem rust epidemics are raging in certain areas of Peru and in certain winter-wheat areas of the upper Midwest of the United States.

6. The control of plant diseases is just as important in the betterment of man's agriculture as is the control of human diseases in the betterment of man himself. The consequences of undernourishment constitute one of the most basic human health problems in many countries, comprising hundreds of millions of people. Every increase in food supplies due to controlling plant diseases is therefore a potential contribution to the improvement of human health and happiness in vast areas of the world.

7. The acute economic and human needs for better control of plant diseases are obvious; the critical question is how they can be controlled. The first requisite is adequate understanding of the causes and nature of the thousands of different diseases that attack the thousands of kinds and varieties of economic plants; the second requisite is to devise ways of combating the disease when it is most vulnerable; the third requisite is to educate agriculturists how best to utilize the best available methods of control; the fourth is continuous research to improve known methods and to devise new ones to control those diseases which hitherto have defied man's scientific knowledge and technical skills; and the fifth requisite is to learn how better to anticipate and counteract the disruptive and destructive effects of new diseases and of old diseases in new areas. The importance and the magnitude of these tasks must not be underestimated.

8. The pathogens that cause plant diseases are very diverse and very shifty. The principal groups are microscopic bacteria and fungi; minute nematodes-eelworms; and viruses, comprising ultramicroscopic particles which behave like living organisms in many ways. All pathogens can develop in living plants and weaken or kill them and some can also destroy plant products, living or dead, such as fruits, fleshy vegetables, seeds, and wood or wood products. Each of the thousands of species may comprise numerous parasitic races, very similar in appearance but different in specific virulence or capacity to produce disease. Thus, the fungus species Puccinia graminis, which causes stem rust of wheat, oats, barley, rye, and several hundred species of wild and cultivated grasses comprises several varieties: the variety tritici can attack wheat and barley but not oats; the variety secalis can attack rye and barley, but not wheat and

oats; and there are several other varieties, each with its own particular ability to attack cultivated small grains or grasses. And within each variety there are numerous parasitic races; within the tritici variety more than 300 have been identified by differences in their effects on 12 varieties of wheat and its close relatives. A variety may be highly resistant to some races and completely susceptible to others. And wheat stem rust is not unique in this respect.

9. Plant diseases are indeed shifty enemies because each pathogenic species is a vast confederation of parasitic races, and new races are continually arising by mutation or by hybridization between existing races. Moreover, the populations of many pathogens are astronomically great and their reproductive power is tremendous. Some viruses can increase a million fold within a few days. Theoretically, a single bacterium can produce a progeny of 300 billion in 24 hours. Fungi produce microscopic reproductive spores, so small that a smutted wheat kernel may contain 12 million and the number in half a dozen heads would equal the number of people in the world. On a single barberry bush there often are about 70 billion cluster-cup spores of wheat stem rust, comprising many parasitic races because the sexual stage of this rust develops on the barberry host. Within a week each cluster-cup spore can produce about 250 thousand summer spores on wheat; and each one of these can produce 250 thousand more of its own kind in another week, thus enabling many old and new parasitic races to increase with amazing and dangerous rapidity. On an acre of moderately rusted wheat there are about 50 thousand billion spores, each one a potential wind-borne menace to healthy wheat hundreds of miles away; for rust spores and those of many other fungus pathogens can be disseminated quickly and widely by the wind. As one example, early in a certain crop season south winds carried invisible billions of rust spores from rusted wheat in south central United States 600 miles northward on a front more than 400 miles wide and infected rust-free wheat in an area of a quarter of a million square miles. Many migrating insects also carry numerous viruses and certain other pathogens long distances when aided in flight by favorable winds. The wind's only competitor for the dishonor of being the champion long-distance distributor of plant pathogens is man himself. Man has done himself irreparable harm by carrying all kinds of plant pathogens, as well as insects and weeds, across barriers to their natural dissemination by wind or other carriers. Many of the most destructive pathogens of all major groups of cultivated and wild plants are where they now are solely because man took them there. And, for several reasons, some pathogens were relatively harmless in the areas whence man took them but were devastating in the areas where he put them.

10. There are four general methods of preventing diseases or reducing losses caused by them: exclusion, eradication, prevention, and immunization.

11. Exclusion in its broadest sense includes all measures designed to keep a pathogen out of a given locality or area, whether by individual action or by official regulation. As many pathogens are distributed within countries and between countries only in or on planting materials, it is important to plant only disease-free ones. Two general kinds of protective measures therefore have been developed: certification and quarantines. Official and semi-official systems of inspection and certification of propagative materials vary greatly in respect of legal regulations and effectiveness in application. Many require official inspection of all commercial seed farms and plant nurseries and prohibit the sale of impure or diseased materials. In other cases inspection and certification are optional with the grower, but purchasers in some countries are sufficiently sophisticated as to buy only certified materials. The need and value of certification are greatest when planting materials look healthy but carry a load of invisible pathogens. Potato tubers, as an example, may look healthy but may be carriers of viruses and other pathogens whose destructive effects are easily visible only on growing plants; hence field inspection by experts is the

prerequisite for certification. Certified potato seed-tubers often yield from 25 to 80 per cent more than ordinary "seed", depending on the prevalence of diseases and the efficiency of the certification service. "Use clean seed" is an agricultural extension slogan in many countries; the injunction should be implemented in all countries. Although good national and international certification programs have reduced losses from diseases, they cannot always be relied upon to exclude certain pathogens from areas in which they do not exist. The resort has been quarantines.

12. Plant quarantines are plant public-health measures. Most countries have suffered disastrous experience because of the introduction of foreign pests and pathogens. More than 50 per cent of the major plant pests and diseases in the United States are of foreign origin, and many other countries can equal this record; consequently, most countries have tried to protect themselves by means of quarantine regulations. Some of the early ones were ill-conceived and poorly executed; however, they have become more rational and realistic as a result of increasing scientific knowledge and experience. Quarantines can be effective. Coffee rust, which devastated coffee plantations of Southern Asia about 70 years ago and still is destructive in the Eastern Hemisphere, has been kept out of the Western Hemisphere by constant vigilance; and many other diseases of both hemispheres have been similarly contained, with very great mutual benefits. Plant quarantines, like most legal restrictions, may be irritating but they are as necessary as those designed to protect the health of domestic animals and of human beings. The criticism that some quarantines have been either misused or ineffective can be made against many measures designed to improve or protect agricultural production. The remedy is to improve them, not to abolish them.

13. Eradication, as a plant public-health measure, is often associated with quarantines. Although the individual grower often practices eradication in "roguing" his fields, the present discussion is restricted to organized governmental attempts to promote plant public-health by destroying pathogens or pests completely or by large-scale eradication of plants which harbor pathogens and constitute a menace to agriculture. Every country needs a "plant-disease survey" agency to obtain information on the occurrence, distribution and destructiveness of old diseases and to detect new pathogens early enough to permit eradication.

14. The results of four eradication campaigns are eloquent of actual and potential accomplishment. Flag smut of wheat was introduced on imported seed wheat into a localized area in Mexico in 1949, and the following year the destruction ranged from 15 to 40 per cent. Mexican authorities promptly burned the infested fields, imposed a three-year embargo on shipment of wheat from the area, and the disease has not appeared subsequently. Likewise, the bacterial citrus-canker disease has been practically eliminated from Florida and neighboring states of the U.S. Introduced from the Orient, the disease was first observed in Florida in 1913. Within a few years state and federal agents destroyed 3 million infested trees by means of a blast-flame, and the disease has not appeared in Florida since 1927. It has either been eradicated completely from the U.S. or reduced to impotence. The destructive cedar rust of apple has long been controlled in certain apple-growing areas of eastern United States by systematic eradication of the red cedar (Juniperus sp.) without which the rust cannot persist.

15. There is a long and variable record of barberry eradication campaigns to control stem rust of wheat and certain other small grains. The first known plant proscription law, enacted in Rouen, France, about 1660, required the destruction of barberry bushes because farmers insisted that rust was always exceptionally destructive near them. Similar observations in various other areas, including several New England colonies of North America, motivated legislation

against the "baneful barberry". The researches of de Bary furnished the scientific explanation, in 1865, of the long-observed baneful effect of the "baneful barberry". It was simple: one stage in the complex life cycle of stem rust develops on barberry, and only on barberry. This discovery stimulated much more anti-barberry legislation. Then the question arose as to whether the barberry stage was essential to the persistence of the rust. A reliable answer had to await extensive investigation. The fact is that rust cannot persist independently of barberry where cold winters force the summer stage of the rust into a dormant overwintering stage, which resumes activity in the spring and can infect only the barberry, on which the sexual stage of the rust develops. From barberry the rust can pass again to wheat and other susceptible grasses and propagate itself in its summer stage so long as summer lasts. In warm, relatively frost-free areas where summer is virtually continuous the rust can persist independently of the barberry.

16. The barberry therefore is a powerful ally of stem rust; it helps it to persist in certain areas, and because it is host to the sexual stage, it is fertile breeding ground for new and dangerous parasitic races. Barberry eradication therefore decreases the amount of rust and reduces the number of kinds or parasitic races of the rust.

17. Barberry eradication has resulted in practical control of stem rust in some areas; in others it has spectacularly reduced the frequency and severity of epidemics; in others it has merely mitigated the annual rust menace; and in most cases it has at least prevented a bad situation from becoming worse. The value of certain programs must be measured not only by comparing the actual present situation with the actual situation in the past but also with the potential present situation: what would the present situation be if the program had not been undertaken? As an example, 296 million barberry bushes were destroyed in the northern United States, 1918-1943. Had these bushes been present during the past 20 years they could have produced, assuming 50% of maximum infection, 9×10^{18} spring spores annually, enough to inoculate the total acreage of wheat in the United States and Mexico with 100 billion spores an acre. But there would also have been far more than 296 million bushes, for they had run wild and were multiplying and spreading rapidly. Moreover, the number of prevalent parasitic races decreased and permitted certain rust resistant varieties to thrive longer than they could have with an abundant source of new races on barberries near every wheat field. We need to sharpen, raise, and broaden our sights with respect to the ultimate values of plant public-health programs.

18. Many diseases can be controlled satisfactorily by treating seeds or by spraying or dusting growing plants with appropriate chemicals. Progress in chemical control has been revolutionary during the past few decades. Many more fungicides are available, many are more effective for certain purposes, and many cause less damage to the seed and plants to which they are applied. A few decades ago a few fungicides were used, like patent medicines, for many purposes; now many more are used, but each one for specific purposes. In the past almost any plant scientist could prescribe fungicides; now it takes an expert. As examples, a certain nurseryman and orchardist lost $10,000 because he followed bad advice and applied a good fungicide to the wrong kinds of plants, but he gained $3,000 in a small apple orchard by following good advice in substituting in the last of four spray applications a better fungicide than he had been using. Of course, these two case histories could be multiplied many fold, both in kind and in magnitude. Research is continually providing new and better chemicals for controlling the numerous kinds of diseases and it is urgent that growers be taught how best to use them and how to avoid misusing them. But this is a job for competent specialists.

19. The only presently practicable way of controlling many diseases is by means of appropriate chemicals. At best, however, most chemicals help prevent but do

not cure diseases, and their effective use adds to the cost of production, sometimes but little and sometimes a great deal. The control of certain smuts and other seed-borne diseases of many crops by seed treatment requires a single simple and inexpensive operation, with a profit of several hundred per cent on the investment. The protection of growing plants, however, often requires several, more expensive operations. Thus, it requires from 10 to 15 spray applications in some areas to protect bananas against destruction by the sigatoka disease, thereby increasing the cost of production about 20 per cent. A single application of a fungicide to potato fields to protect them against late blight costs about $3.00 an acre. As 10 applications are necessary in many areas, the cost of protection is $30 an acre. But certain semi-resistant varieties have been protected by 4 applications, at a cost of $12 an acre; hence the resistance has saved the grower $18 an acre.

20. The ideal way of controlling all plant diseases would be by means of resistant varieties, both to reduce the cost of production and to control many extremely destructive diseases that cannot now be controlled economically by any other means. Every contribution that the plant can make to its own protection against disease relieves man of just that much worry, work, and expense in protecting them. The need for resistant varieties is evident, but how feasible is it to produce them? There is no simple, categorical answer.

21. The degree of success in programs of breeding for disease resistance has varied widely: some were completely successful, some were partly or temporarily successful, and others were relative or complete failures. But much was learned, both from the successes and from the failures. And it is essential to progress that we profit by the lessons learned from both. The scientific foundation for rational procedures in breeding for resistance began to be laid about 50 years ago, and it is still in process of construction. At least we have learned enough not to repeat past mistakes and to improve concepts and procedures.

22. The general lesson learned from past experiences is that breeding programs must be more broadly based, because most crop plants and their pathogens are broadly based. There are thousands of varieties of wheat, rice, maize, sorghums, sugarcane, potatoes, and of most other important food or feed crops in the world, with many different degrees of susceptibility or resistance to diseases. And there are hundreds of species of pathogens, each comprising numerous parasitic races, with different degrees of virulence for species or varieties of crop plants. The genes for disease resistance and other desirable characters are scattered in many varieties in many parts of the world; and the genes for virulence are scattered in many parasitic races in many parts of the world. The problem is to locate, assemble, and combine the genes for resistance into new varieties and test them against an adequate sample of pathogens under an adequate sample of environmental conditions. Unless this is done the new varieties are likely to be disappointing. After having been grown for a few years, many varieties were found to be exceptionally susceptible to diseases other than those against which they were bred or to have merely temporary, local, or variable resistance to those against which they were bred. Disappointments should be restricted to experimental plots; they are too painful when suffered on thousands of farms.

23. Successful breeding for disease resistance usually requires cooperation between geneticists and pathologists. It is unscientific to engage in a breeding program without adequate knowledge of what is being bred and against what it is being bred; the geneticist or plant breeder must know the varieties of the crop plant and the pathologist must know the number, distribution, and degree of virulence of the parasitic races of the pathogen. The plant selections or hybrids must then be exposed to infection by an adequate sample of the parasitic races, under conditions that permit them to do their worst. This is not easy but it is

essential. Many varieties have succumbed to parasitic races against which they had not been tested before distribution; and many were resistant under the environmental conditions of the breeding plots but not under those which they encountered in other localities. The ideal is to locate, collect and identify all parasitic races in the region in which the variety is to be grown, then inoculate the breeding nursery with them under conditions which permit rigid selection. The resistant lines should then be further tested at different temperatures and other conditions in plant houses to ascertain the possible variability in their resistance. When facilities are not available for an ideal program, nurseries should at least be inoculated with a composite sample of diseased materials from many varieties and several localities in the area, in the hope of including an adequate sample of important pathogens and their parasitic races. The selected lines should then be tested in several seasons and at several places.

24. International cooperation can aid greatly in improving disease control by means of resistant varieties. Varieties may be highly resistant to all parasitic races of the pertinent pathogen in one country but susceptible to those in another. If the pathogen is not distributed by wind or other agents of dissemination beyond the control of man, they can be excluded by quarantine or other phyto-sanitary regulations. Those which are wind-borne, however, are likely to spread sooner or later to all countries within homogeneous geographic areas. International cooperation in testing and breeding of varieties can therefore be mutually beneficial. Indeed, it is essential to most rapid and permanent progress.

25. Disease resistant varieties have been of incalculable value in all countries where available scientific knowledge and technical skills were utilized in breeding programs. In the United States, flax wilt, cabbage yellows, and several other wilt diseases have been kept under control for almost 50 years; the sugar beet industry of western United States was saved from annihalation by means of varieties resistant to virus curly top; and losses from some major diseases of virtually all major crop plants have been substantially reduced. The spring bread wheat area of northern U. S. and Canada has been protected against the scourge of stem rust in about 20 years of the past 40, not a perfect record but a good one. Within the past 20 years wheat production has been doubled in Mexico, as a result of the production of superior, rust-resistant varieties and better cultural methods. Several western European countries have improved and partly insured agricultural production similarly.

26. Much still remains to be learned about plant-disease control, but what has been learned should be utilized as fully and as widely as possible. It is hard for a teacher to teach what he does not know. The transmission of successful experiences from those countries which have had them to those which have not is a job for competent specialists.

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